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Strain Testing: Northrop Grumman Standoff Project

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Project Background

- Standoffs are bonded to motor domes using adhesive
- Adhesive is applied and bracket is taped to hold during curing process
- Taping is unreliable and costs money and man hours when it fails
- Analyze and build a prototype that will hold standoff brackets in place while adhesive cures

Figure 1. Castor 50XL [1]

Figure 2. Castor 30XL [1]

Design Description

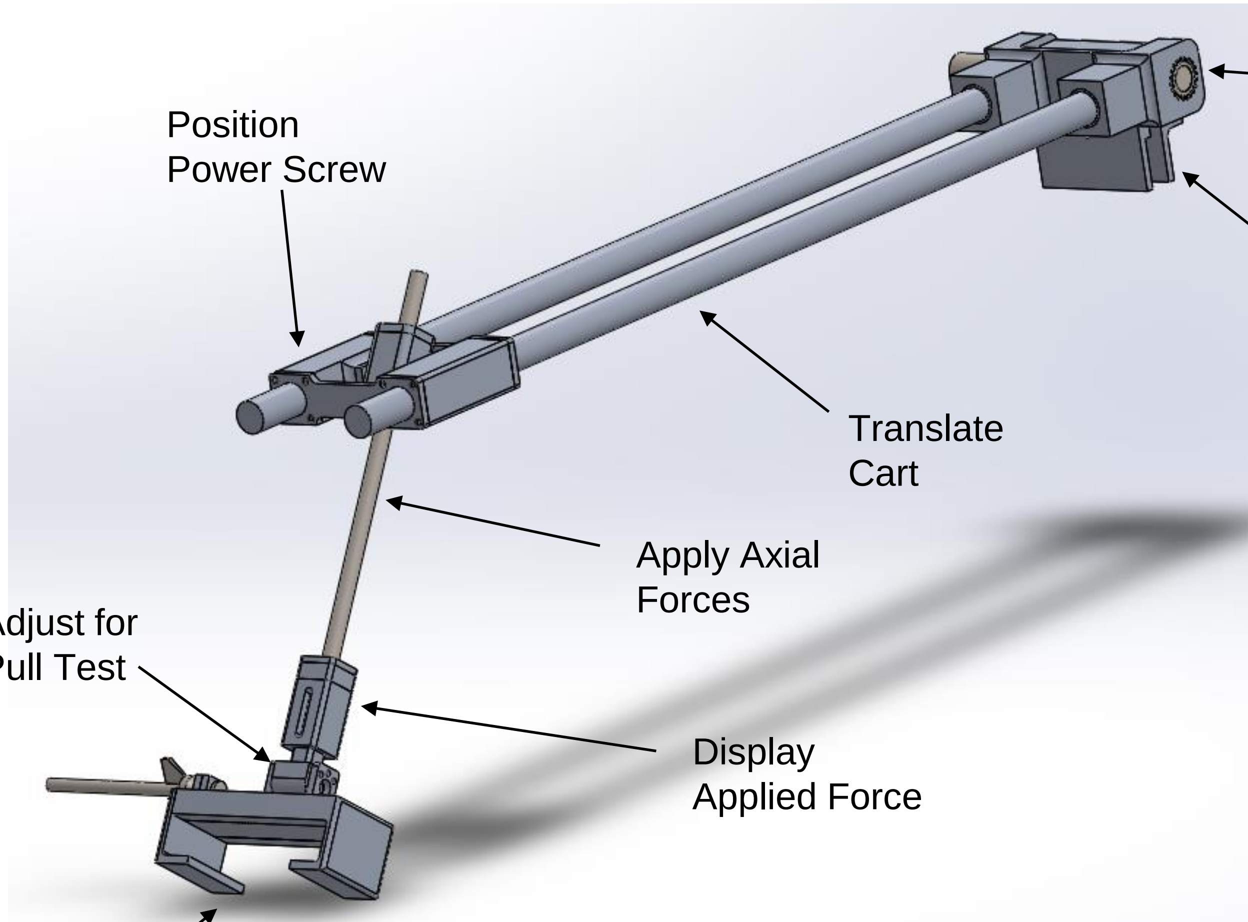

Figure 3. Current CAD Model

Rail System

- Two sets of cylindrical rails allow the cart to slide inward from the hinge component
- Inboard 4”-36” from the motor ring

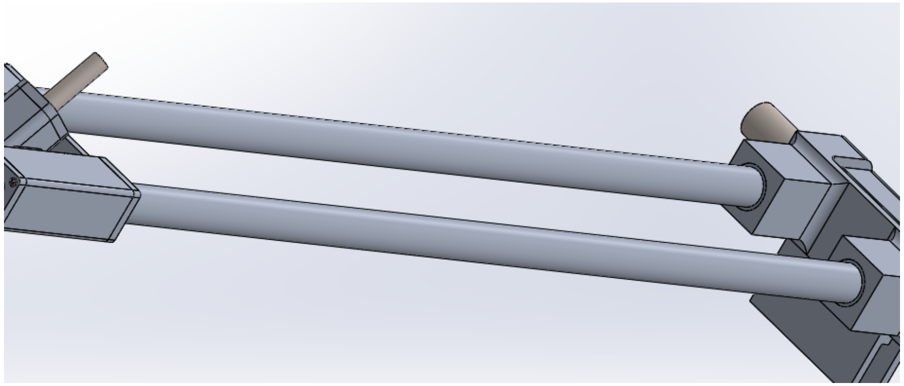

Figure 4. Rail System

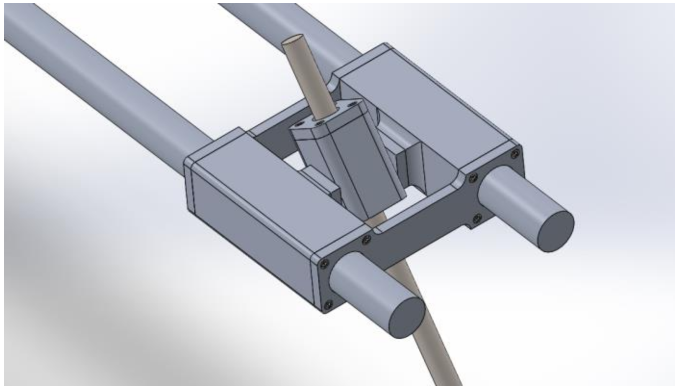

Figure 5. Rail Cart and Angleable Lead Screw

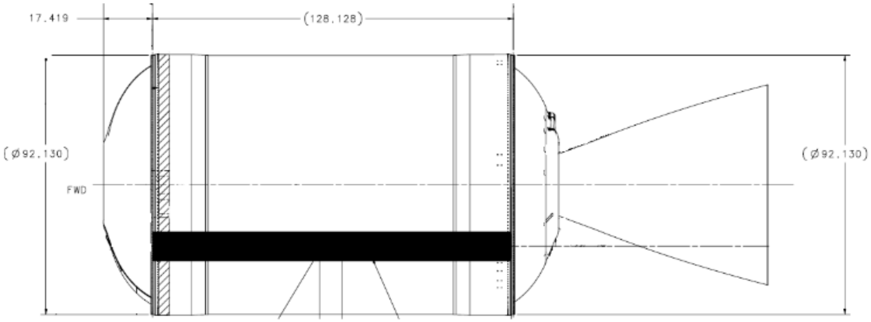

Figure 6. Castor 30 Series Drawing

Experiment Objectives

1) Determine the resulting strain of the test specimens
2) Compare analytical methods to strain gauge results
3) Expand skill set into manufacturing and EE disciplines
    a) Wheatstone Bridge Setup and Use
    b) Machine Shop Lathe Practice
    c) Soldering Experience

Known Values

Table 1: Known Values for Test Specimens

Geometric Values			
6061 Aluminum (E = 69 GPa) [2]		4130 Steel (E = 205 GPa) [3]	
Length (in)	9.0625	Length (in)	7.15625
Length (m)	0.2301875	Length (m)	0.18176875
Diameter (in)	0.251	Diameter (in)	0.235
Diameter (m)	0.0063754	Diameter (m)	0.005969

Table 2: Experimental Values

Input Voltage (V)	0.05
Room Temperature (°C)	18.5
Water Density (kg/m^3)	998.501 [4]
Bucket Mass (kg)	0.907

Expected Strain Calculations

Calculated Strain:

$E = \frac{\sigma}{\varepsilon}$	(Modulus of Elasticity Definition)
$M_W = \rho V$	(Mass of Water)
$m = M_B + M_W$	(Total Mass)
$F = m g$	(Gravitational Force)
$M_x = F L$	(Bending Moment on Beam)
$\sigma = \frac{M_x \left(\frac{d}{2}\right)}{I_C}$	(Bending Stress on Beam)
$I_C = \frac{\pi}{32} d^4$	(Moment of Inertia)
$\varepsilon = \frac{(M_B + \rho V) g L}{\frac{\pi}{16} d^3 E_i}$	(Final Calculated Strain Equation)

Variables:

$M_B = \text{Mass of Bucket}$

$\rho = \text{Water Density Room Temperature}$

$V = \text{Volume of Water}$

$g = \text{Gravitational Acceleration}$

$\varepsilon = \text{Strain}$

$L = \text{Length}$

$d = \text{Beam Diameter}$

$E_i = \text{Input Voltage}$

Strain Gauges

- Compare theoretical strain to experimental strain
- Micro-Measurements Precision Strain Gauges
- Gauge Factor : 2.1 ± 0.5%
- Gauge Resistance: 120Ω
- Required Detailed Soldering Skills to Implement

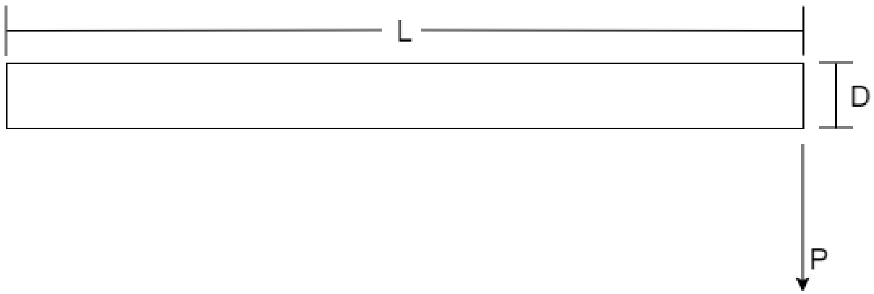

Figure 7. Cantilever Force Diagram

Figure 8. Strain Gauges

Measured Strain Calculations

Variables:

$$\delta E_O = \textit{Change in Voltage Out}$$

$$GF = \textit{Gauge Factor}$$

$$\varepsilon = \textit{Measured Strain}$$

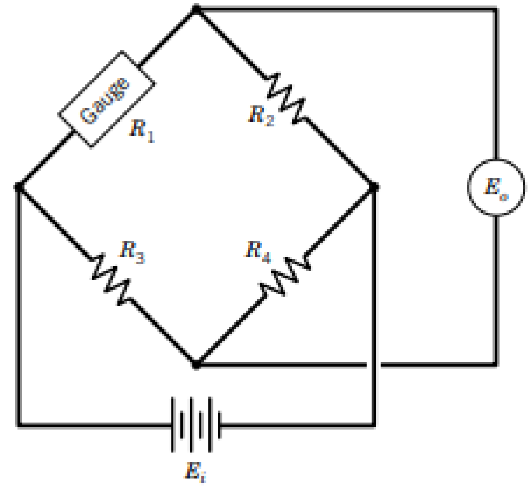

Figure 9. Quarter Bridge Wheatstone Set-up

Measured Strain :

$$(\varepsilon_1 - \varepsilon_2 + \varepsilon_4 - \varepsilon_3) = \frac{\delta E_O\, GF}{4\, E_i}$$ (Strain Gauge Relation)

$$\varepsilon = \frac{4(E_{02} - E_{01})}{GF\, E_i}$$ (Final Measured Strain Equation)

Experiment Materials

Soldering Iron	Lead Wires
Digital Caliper	9213 DAQ
Graduated Cylinder	LabView VI
DC Power Supply	C-Clamp
Prototyping Board	Test Specimens
Resistors	Tape
Strain Gauges	Bonding Agent
Specimen Holder	Degreaser and Neutralizer

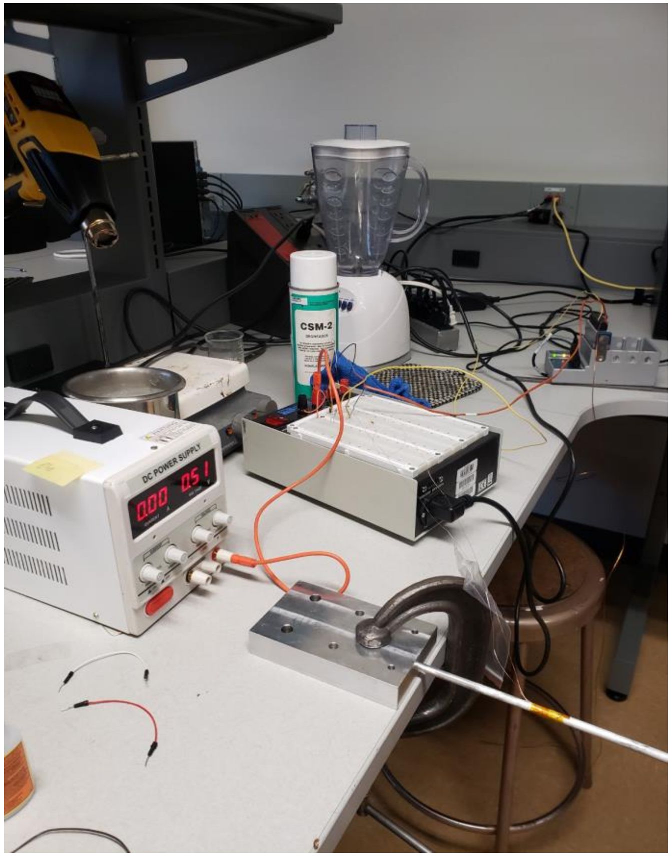

Figure 10. Experimental Setup

Soldering Experts

- Extremely small pads required a microscope to effectively attach lead wires
- Small lead wires needed to be soldered to larger wire to fit the DAQ equipment

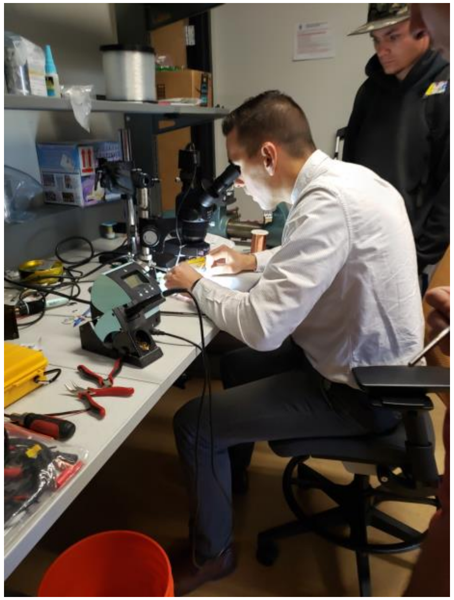

Figure 11. Dr. Shafer Soldering

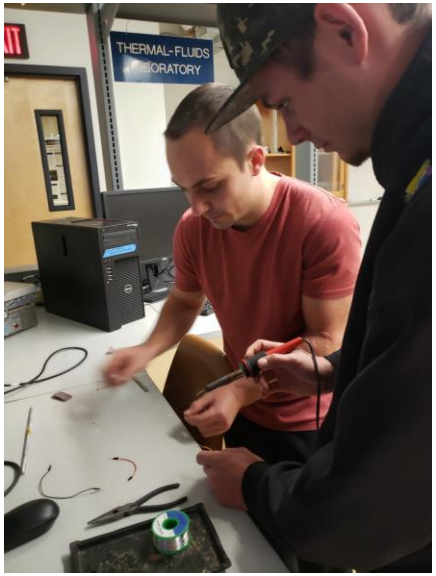

Figure 12. Team G2 Soldering

Setting up the Weight

- Utilized water volumes as applied load
- Measured room temperature to determine accurate water density
- Converted known volume measurements to water mass
- Known mass of bucket and wire system

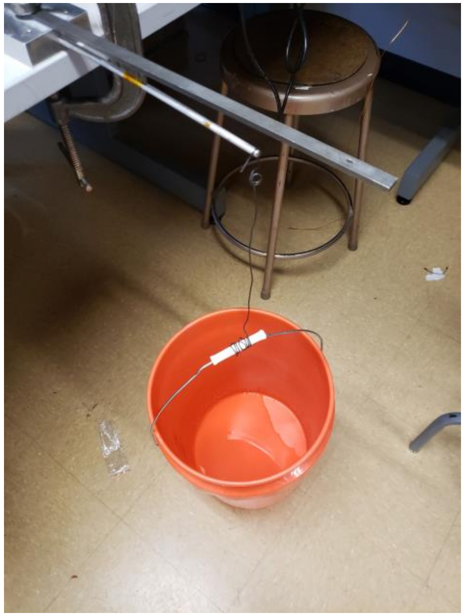

Figure 13. Bucket Set-up

Figure 14. Steel Rod Strain Gauge

Wheatstone Bridge Setup

- Quarter Bridge setup allowed the team to calculate strain in a single gauge
- Three 100Ω resistors with a 120Ω strain gauge
- DC Power Supply for Vin
- LabView to read Vout

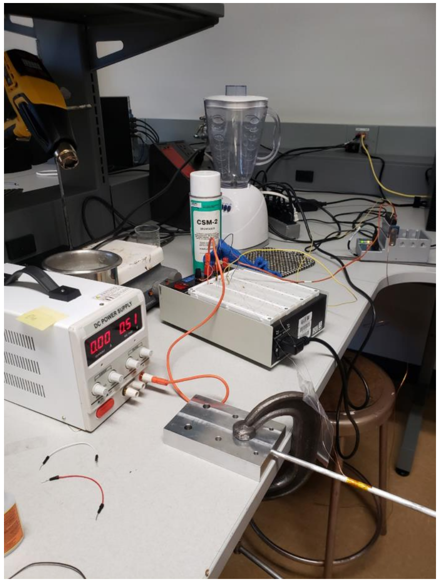

Figure 15. Electrical Components

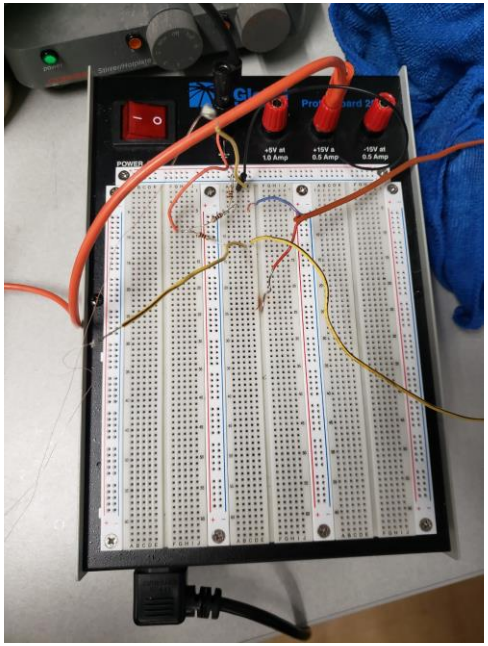

Figure 16. Wheatstone Bridge

LABVIEW VI

- Utilized a modified Lab 5 VI to measure Vout
- Removed temperature and waveform graphs
- Set DAQ to read maximum voltage: ±78.2 mV

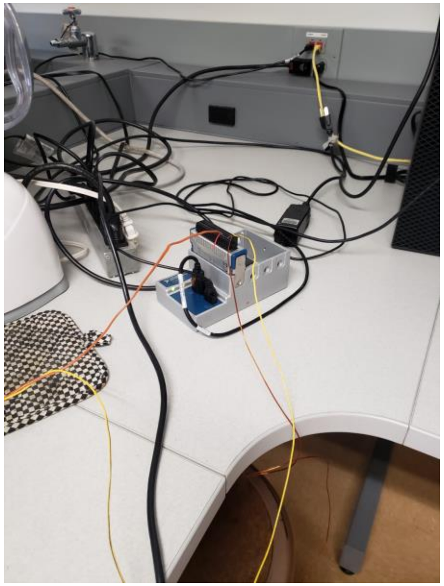

Figure 17. DAQ Set-up

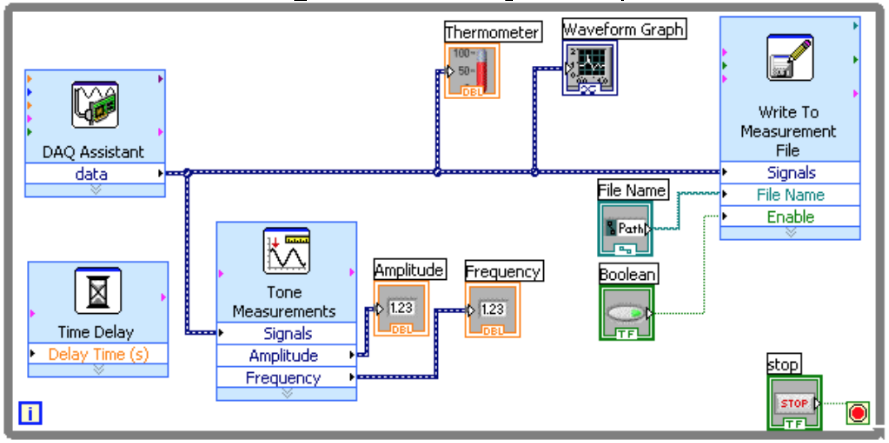

Figure 18. LABVIEW Set-up

Percent Errors for Strain Measurements

Table 3. Percent Errors for Calculated and Measured Strain

4130 Steel				6061 Aluminum			
Load (kg)	Calculated Strain	Measured Strain	Percent error	Load (kg)	Calculated Strain	Measured Strain	Percent error
0	0	0	0.00	0	0	0	0.00
0.907	0.000188933	0.000228571	20.98	0.907	0.000583387	0.00056	4.01
1.406	0.000292929	0.000350476	19.65	1.157	0.000743947	0.000651429	12.44
1.905	0.000396925	0.000453333	14.21	1.406	0.000904507	0.000761905	15.77
2.404	0.000500922	0.000579048	15.60	1.656	0.001065068	0.000925714	13.08
2.904	0.000604918	0.000693333	14.62	1.905	0.001225628	0.001062857	13.28
3.403	0.000708915	0.000807619	13.92	2.155	0.001386188	0.00119619	13.71
3.902	0.000812911	0.000895238	10.13	2.404	0.001546748	0.001321905	14.54
4.401	0.000916907	0.000982857	7.19	2.654	0.001707309	0.001466667	14.09
5.899	0.001228897	0.001340952	9.12	2.904	0.001867869	0.001607619	13.93

Uncertainty Equations

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Calculated Strain Equation:

$$\varepsilon = \frac{(M_B + \rho V)\, g\, L}{\frac{\pi}{16}\, d^3\, E_i}$$

Calculated Strain Uncertainty:

$$\frac{\delta\varepsilon}{\delta M_B} = \frac{16\, L\, g}{\pi\, d^3 E}$$ (Partial in Respect to Mass of Bucket)

$$\frac{\delta\varepsilon}{\delta V} = \frac{16\, L\, \rho\, V}{\pi\, d^3\, E}$$ (Partial in Respect to Water Volume)

$$\frac{\delta\varepsilon}{\delta L} = \frac{16\, g\, (M_B + \rho\, V)}{\pi\, d^3\, E}$$ (Partial in Respect to Length)

$$\frac{\delta\varepsilon}{\delta d} = \frac{-48\, L\, g\, (M_B + \rho\, V)}{\pi\, d^4\, E}$$ (Partial in Respect to Diameter)

Variables:

M_B = *Mass of Bucket*

ρ = *Water Density Room Temperature*

V = *Volume of Water*

g = *Gravitational Acceleration*

ε = *Strain*

L = *Length*

d = *Beam Diameter*

E_i = *Input Voltage*

Calculated Strain Error Propagation (Aluminum)

Table 4. Calculated Strain Error Propagation (Aluminum)

Calculated Strain at Max Load (6061 Aluminum)					
Measurement	Value	Uncertainty	Units	Partial Derivative Value	Derivative*Uncertainty Squared
Mass of Bucket	0.907	0.2204	kg	0.000643205	2.00966E-08
Water Volume	0.002	0.000005	m^3	0.64224089	1.03118E-11
Length of Rod	0.2301875	0.00079375	m	0.008114553	4.14855E-11
Diameter of Rod	0.0063754	0.0000254	m	-0.878941916	4.98411E-10
				Total Uncertainty	0.00014369

Calculated Strain at Max Load (Al)		
0.0018679	±	0.00014369

Calculated Strain Error Propagation (Steel)

Table 5. Calculated Strain Error Propagation (Steel)

Calculated Strain at Max Load (4130 Steel)					
Measurement	Value	Uncertainty	Units	Partial Derivative Value	Derivative*Uncertainty Squared
Mass of Bucket	0.907	0.2204	kg	0.000618877	1.86051E-08
Water Volume	0.002	0.000005	m^3	0.617949542	9.54654E-12
Length of Rod	0.18176875	0.00079375	m	0.009887402	6.15931E-11
Diameter of Rod	0.005969	0.0000254	m	-0.903277303	5.26392E-10
				Total Uncertainty	0.000138574

Calculated Strain at Max Load (Steel)		
0.0012289	±	0.00013857

Uncertainty Equations

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Measured Strain Equation:

$$\varepsilon = \frac{4(E_{02} - E_{01})}{GF\ E_i}$$

Measured Strain Uncertainty:

$$\frac{\delta\varepsilon}{\delta E_{02}} = \frac{4}{GF\ E_i}$$

(Partial in Respect to Voltage Out)

$$\frac{\delta\varepsilon}{\delta E_{01}} = \frac{-4}{GF\ E_i}$$

(Partial in Respect to Initial Voltage Out)

$$\frac{\delta\varepsilon}{\delta GF} = \frac{-4(E_{02} - E_{01})}{GF^2\ E_i}$$

(Partial in Respect to Gauge Factor)

$$\frac{\delta\varepsilon}{\delta E_i} = \frac{-4(E_{02} - E_{01})}{GF\ E_i^2}$$

(Partial in Respect to Voltage In)

Variables:

δE_O = *Change in Voltage Out*

GF = *Gauge Factor*

ε = *Measured Strain*

Measured Strain Error Propagation (Aluminum)

Table 6. Measured Strain Error Propagation (Aluminum)

Measured Strain at Max Load (6061 Aluminum)					
Measurement	Value	Uncertainty	Units	Partial Derivative Value	Derivative*Uncertainty Squared
Voltage In	0.05	0.01	V	-0.032152381	1.03378E-07
Gauge Factor	2.1	0.0105		-0.000765533	6.4611E-11
Voltage 1	0.0021406	0.0000001	V	-38.0952381	1.45125E-11
Voltage 2	0.0021828	0.0000001	V	38.0952381	1.45125E-11
				Total Uncertainty	0.000321669

Measured Strain at Max Load (Al)		
0.0016076	±	0.00032167

Measured Strain Error Propagation (Steel)

Table 7. Measured Strain Error Propagation (Steel)

Measured Strain at Max Load (4130 Steel)					
Measurement	Value	Uncertainty	Units	Partial Derivative Value	Derivative*Uncertainty Squared
Voltage In	0.05	0.01	V	-0.026819048	7.19261E-08
Gauge Factor	2.1	0.0105		-0.000638549	4.49538E-11
Voltage 1	0.0021269	0.0000001	V	-38.0952381	1.45125E-11
Voltage 2	0.0021621	0.0000001	V	38.0952381	1.45125E-11
				Total Uncertainty	0.000268328

Measured Strain at Max Load (Steel)		
0.0013410	±	0.00026833

Discussion

- Two different methods to calculate strain
- Differences in measurements are within the uncertainty ranges
- Uncertainties for the strain gauge measurements were more significant

Calculated Strain at Max Load (Al)		
0.0018679	±	0.00014369

Measured Strain at Max Load (Al)		
0.0016076	±	0.00032167

Calculated Strain at Max Load (Steel)		
0.0012289	±	0.00013857

Measured Strain at Max Load (Steel)		
0.0013410	±	0.00026833

Ways to Improve

- Balanced Wheatstone Bridge
  - Would allow for larger input voltage
- Finer Manufacturing Tolerances
  - Specimen length caused deflection in the center while on the lathe
  - Fit between the rod and the drilled hole
- More precise scale to measure the weight of the bucket and wire

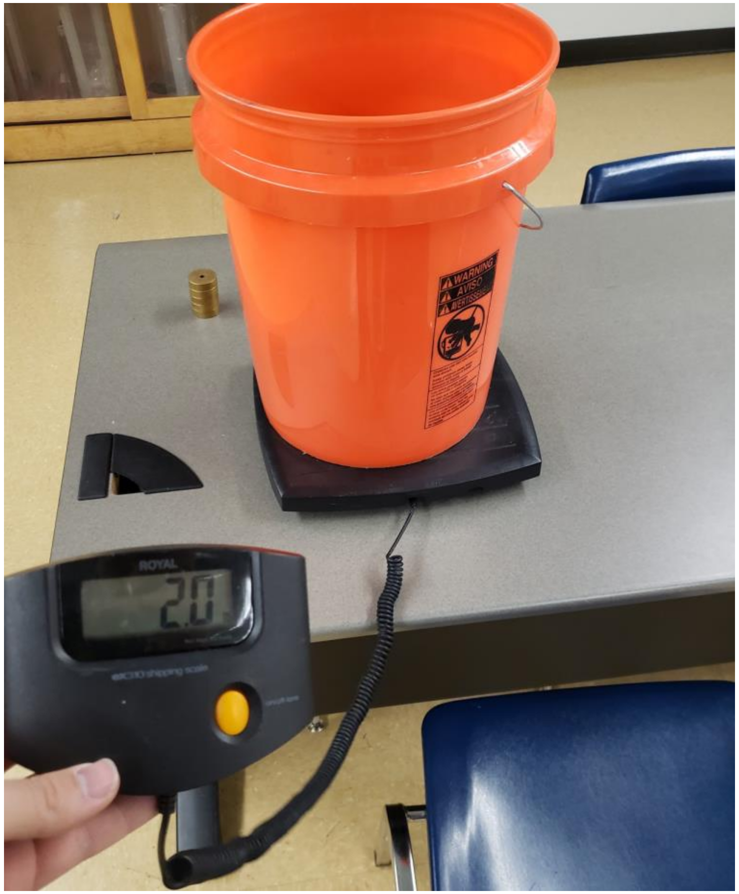

Figure 19: Scale used in the Experiment

Conclusion

- The objective of this lab was to determined the strain of Aluminum 6061 and Steel 4130
- Compared analytical and strain gauge methods to verify the experiment results
- Determined the error propagation for both the calculated and measured strain values
  - Uncertainties for the strain gauge measurements were more significant
- There are methods to improve the experiment in the future
  - Balanced Wheatstone Bridge
  - Finer Machining Tolerances
  - More precise scale

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References

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[1] *Propulsion Products Catalog*, Northrop Grumman, Falls Church, VA, June 2018

[2] "Aerospace Specification Materials," MatWeb, [Online]. Available: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=MA6061T6. [Accessed 4 December 2019].

[3]"Aerospace Specification Materials," MatWeb, [Online]. Available: http://asm.matweb.com/search/SpecificMaterial.asp?bassnum=m4130r. [Accessed 4 December 2019].

[4] J. Rumble, in Handbook of Chemistry and Physics, CRC Press, 2019